2021

Evaluation of Compressor Reliability for HFO Refrigerants

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ABSTRACT

Responses to an international flamework on climate change, such as the Kigali Agreement in 2016, have been discussed in an industrial field. The phase down regulation of CFC and HCFC refrigerant has been discussed and performed under the Montreal Protocol for refrigerants from the viewpoint of ozone layer protection. From the viewpoint of preventing global warming, HFC reduction plans are currently being proposed by North America, Europe, India, etc. within the framework of the Protocol. A developing country where the phase-out of CFCs and HCFCs began in 2013, are growing trend to switch to HFC or HFO mixed refrigerants with lower GWP than R410A. A revision of the regulations related to HFC are also being promoted in each region.

The GWP upper limit for each equipment application was set together with the HFC phase down in Europe which due to the F-gas regulations. R32, HFO refrigerants such as R1234yf and R1234ze, or a mixed refrigerant of HFC and HFO are proposed as candidates for low GWP refrigerants. The problem of R32 was the higher discharge gas temperature than R410A, but the problem could be solved by temperature control and suitable refrigeration oil.

On the other hand, the problem of refrigerants HFO and mixed HFO is easy to decompose than HFC. When HFO is decompose, it is generated acid such as fluorinated acid and trifluoroacetic acid. These acids make which is reduced the compressor reliability. We selected of suitable refrigeration oil and materials for the HFO and confirmed the compressor reliability

1. INTRODUCTION

Phase down regulations for CFC and HFC refrigerants are being implemented from the perspective of preventing global warming, and F-gas regulations, etc., necessitate equipment development that is compatible to low global warming potential (GWP) refrigerants for each equipment application [1]. While each of the low GWP refrigerant candidates, including R32, HFO, and HFO blends, has its own issues, Daikin Industries has already addressed the issues related to R32 and is currently marketing R32 products [2]. This paper focuses on the HFO and HFO blend refrigerants, which are among other candidates for alternative refrigerants, and reports on results for confirming the reliability of product systems and compressors by selecting refrigeration oil suitable for the single-component refrigerants R1234yf and R1234ze, which are HFO refrigerants, as well as the refrigerants containing them.

2. Issues of HFO and HFO Blend Refrigerants

Tables 1 and 2 show the characteristics of HFO and HFO blend refrigerants and Table 3 shows their issues. HFO refrigerants easily decompose due to their low GWP, and the decomposed product can lead to such problems as deterioration in the stability of refrigeration oil, wear of sliding parts, and corrosion of the expansion valve.

Table 1: Characteristics of R410 Alternative Refrigerants Including HFO Blends

		Current	Alternative refrigerant candidates		
		R410A	R32	R454B	AMOLEA 400X
Refrigerant Composition	R32	50wt%	100wt%	68.9%	
	R125	50wt%			
	R1234yf			31.1%	
	R1123				
Refrigerant Properties	GWP (IPCC4)	2090	675	466	405
	Flammability and Toxicity	A2L	A2L	A2L	A2L

Table 2: Characteristics of R134a Alternative HFO and HFO Blend Refrigerants

		Current	Alternative refrigerant candidate		
		R134a	R1234yf	R1234ze	R513A
Refrigerant Composition	R134a	100wt%			44wt%
	R1234yf		100wt%		56wt%
	R1234ze			100wt%	
Refrigerant Properties	GWP (IPCC4)	1430	4	6	573
	Flammability and Toxicity	A1	A2L	A2L	A1

Table 3: Technical Issues of HFO Refrigerant Air Conditioning Systems

Elements	Technical Issues
Refrigerant	・Chemical Stability
Compressor	・Wear (Corrosive Wear)
Refrigeration Oil	・Miscibility with HFO Refrigerant ・Chemical Stability ・Mixture Viscosity
Motor Materials	・Compatibility with HFO Refrigerants Refrigerant & Lubricant ・Thermal Stability
Refrigeration Cycle	・Corrosion in Expansion Valve ・Capillary Tube Clogging ・Influence of Process Materials ・Decrease in Volume Capacity

3. Selection of Refrigeration Oil Used for HFO and HFO Blend Refrigerants

3.1 Refrigerant stability

To investigate the specifications of refrigeration oil, the stability of single-component refrigerants was confirmed by the shield tube test. Table 2 shows the test conditions and Figure 1 shows the test results. Although there was no decomposition for HFO refrigerants R1234yf and R1234ze under conditions with no air and water or with only water, R1234ze and R1234yf decompose more easily than R32 when air (oxygen) is present. The amount of detected acid follows in order of R22 > R1234yf > R1234ze > R32. As shown in Scheme 1, when R1234ze and R1234yf decompose, strong acids such as hydrofluoric acid and trifluoroacetic acid are generated and cause expansion valve corrosion, capillary clogging, and abnormal wear. Consequently, it is necessary to select refrigeration oil and materials that are resilient to the effects of the strong acid generated by the decomposition of HFO refrigerants.

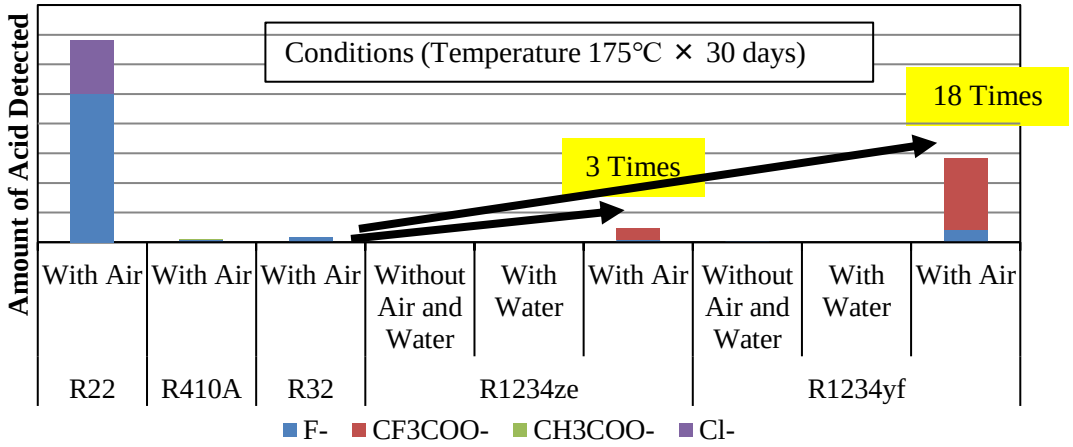
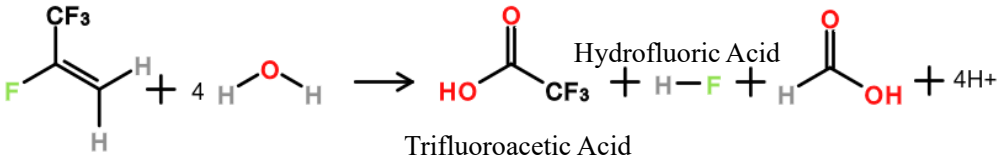


Figure 1: Detected Ratio of Various Acids after Refrigerant Stability Test



Scheme 1: Decomposition Reaction of R1234yf

3.2 Investigation of refrigeration oil specifications

Stability is an issue for HFO refrigerants. For this reason, it is important to select a base oil with high stability and include an additive mixture that can neutralize the decomposition product of the refrigerants. Because HFO refrigerants have no compatibility problem with refrigeration oil, it is possible to use polyvinyl ether (PVE) and polyol ester (PVE), which are used for conventional HFC refrigerants. PVE, which excels in compatibility with HFO refrigerants, hydrolyzability, and lubricity and is the same oil used for R32, was used as the base oil [3]. Because HFO refrigerants decompose more easily than R32, a combination of additives and a new stabilizer were employed to suppress HFO refrigerant decomposition. Table 4 shows the mixture of additives that was used in the oil for the HFO refrigerants.

Table 4: Refrigeration Oil Additive Specifications for HFO and HFO Blend Refrigerants

	Refrigeration Oil for HFO Refrigerant
Extreme Pressure Agent	Same as that for R32
Antioxidant Agent	Same as that for R32
Acid Catcher Agent	Same as that for R32
New Stabilizer	Added

4. Refrigeration Oil Lubricity Test Results

Lubricity was tested with a ring-on-disk test using the selected refrigeration oil. Table 5 shows the test conditions, whereas Figure 2 and Table 6 show the test results. Evaluation was performed for a test piece with a ring made of cast iron and disks made of cast iron and aluminum alloy. For cast iron, the surface pressure for R454A and Current-PVE, which is used with R410A, was equivalent to that of R410A and Current-PVE, and good lubrication properties were confirmed for R454B and R1234yf using New-PVE, which is used for HFO refrigerants. For the aluminum alloy, lower surface properties were seen for Current-PVE, but the combination of New-PVE and R454B demonstrated surface properties comparable to R410A and Current-PVE. A large amount of fluoride ions was detected on the aluminum alloy surface by EPMA mapping of the aluminum alloy surface after the test, but detection of fluoride ions was suppressed for New-PVE and R454B. For R454B and Current-PVE, we believe that the R1234yf contained in R454B reacted with the aluminum surface to generate

aluminum fluoride, and this caused a reduction in lubricity. However, for R454B and New-PVE, the new stabilizer effectively suppressed a reaction between R1234yf and the aluminum surface, thereby preventing the formation of aluminum fluoride, and exhibited lubricity comparable to that of R410A and Current-PVE. Consequently, we selected New-PVE as the refrigeration oil to be used with HFO refrigerants and performed tests to confirm its refrigeration cycle reliability.

Table 5: Conditions of Max Loading Surface Test

Refrigerant	R410A or R454B	
Sliding Velocity	3.5 m/s	
Load	From 0 MPa until the test stops (Up to 10MPa)	
Ring material	Cast iron	
Disk material	Cast iron	Al-Alloy

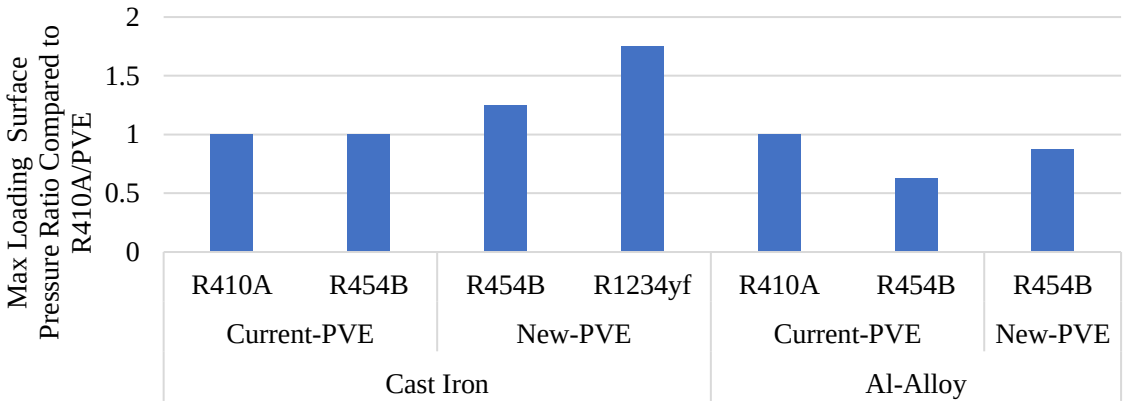
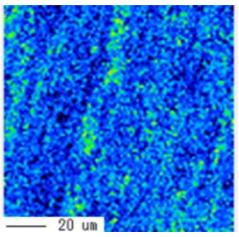
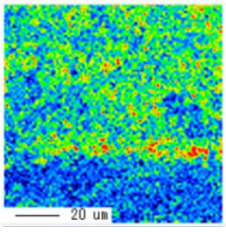
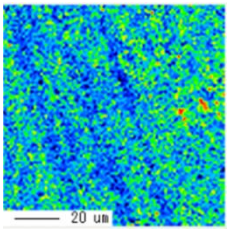
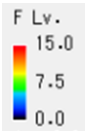


Figure 2: Results of Lubricity Conformation

Table 6: EPMA Mapping Image of Cast Iron and Al-Alloy

	R410A/Current-PVE	R454B/Current-PVE	R454B/New-PVE	scale
Al-Alloy				

5. Reliability Confirmation Results of HFO and HFO Blend Refrigerants in the Refrigeration Cycle by Drop-in Test

5.1 Confirmation results of system reliability by HFO blend drop-in test (Mini-split Air Conditioner)

To verify applicability to refrigerant systems employing HFO blends, a drop-in test was performed on a 2.8 kW R32 refrigerant system. Table 7 shows test conditions and Table 8 and Table 9 show test results. While discoloration and corrosion were seen in the expansion value for PVE and R410A, discoloration and corrosion were not seen for PVE and HFO refrigerants, and there was also no discoloration in the oil. Additionally, in the test used for PVE and R410A, acid is generated in the refrigeration oil, and the HFO refrigerants are believed to decompose in the system, causing corrosion from the decomposition product. In contrast, because the formation of acid is suppressed in PVE and HFO refrigerants, we believe that this demonstrates the effect of the additive.

Table 7: Conditions of System Drop-in Test

Test No.	No. 1	No. 2
System	2.8 kW System for R32	
Refrigerant	R454B	
Compressor Type	Swing Compressor for R32	
Casing Pressure	High Pressure Dome Casing Type	
Rotational Speed	Variable	
Refrigeration Oil	Current-PVE	New-PVE
Additive	Same as additive used in PVE for R410A	New stabilizer added
Expansion Valve	Electric Expansion Valve (Material: Cu-Zn Alloy (Brass)	
Discharge Gas Temperature	120ºC Max.	
Operating Time	1000 hours	

Table 8: Results of System Drop-in Test

Test No.	No. 1	No. 2
Expansion Valve	Corroded	No Problem
Refrigeration Oil		
Acid Number	0.02 mg KOH/g	0.01 mg KOH/g
Fluorine ion	>1 mg/L	>1 mg/L
Trifluoroacetic ion	>1 mg/L	>1 mg/L
Acetic acid ion	2 mg/L	2 mg/L

Table 9: Expansion Needle Valves after System Drop-in Test (Needle Material: Cu-Zn Alloy [Brass])

	No. 1	No. 2
Appearance		
Detected Fluorine by EPMA	16.2 wt%	0.9 wt%

5.2 Confirmation Results for System Reliability by HFO Refrigerant Drop-in Test (Screw Chiller)

To verify applicability to HFO refrigerant systems, a drop-in test was performed on a 100kW R134a screw chiller. Table 10 shows the test conditions, and Table 11, Table 12, and Figure 2 show the test results. No corrosion was observed in the expansion valve, motor, screw rotor, and gate rotor after the test. The oil showed no rise in acid number after the test, and there was no acid formation derived from refrigerant decomposition product.

Table 10: Conditions of System Drop-in Test

Test No.	No. 3
System	Screw Chiller
Refrigerant	R1234ze
Compressor Type	Screw Compressor 100kw
Rotational Speed	Variable
Refrigeration Oil	New-PVE
Additive	New stabilizer added
Expansion Valve	Electric Expansion Valve (Material: Cu-Zn Alloy [Brass])
Discharge Gas Temperature	120 ºC MAX
Operating Time	2000 hours

Table 11: Results of System Drop-in Test

Test No.	No. 3
Expansion Valve	No Problem
Compressor	No Problem
Refrigeration Oil	
Acid Number	0.02 mg KOH/g
Fluorine ion	>1 mg/L
Trifluoroacetic ion	>1 mg/L
Acetic Acid ion	>1 mg/L

Table 12: Appearance of Refrigeration Oil after System Drop-in Test

Time	0 hour	957 hours	2000 hours
Appearance of Refrigeration Oil			

(A)

(C)

Figure 3: (A) Motor, (B) Expansion valve, (C) Screw rotor, (D) Gate rotor, after System Drop-in Test

5.3 Confirmation Results of Scroll Compressor Reliability by HFO Blend Drop-in Test

To verify compressor reliability for HFO blends, an HFO blend refrigerant was dropped into an R32 scroll compressor, and a durability test was performed. Table 13 shows the test conditions and Table 14 shows the test results. Worsening of shaft surface roughness and abnormal bearing wear were not observed even under conditions of high discharge gas temperature for which refrigerant decomposition is a concern. Also, the oil showed no increase in acid number after the test, and there was no acid formation derived from refrigerant decomposition product.

Table 13: Durability Test Conditions of Scroll Compressor

Test No.	No. 1	No. 2	No. 3
Operating Conditions	High Compression Ratio	Max Speed, Wet	Overload Wet, On-off Action
Operating Time	400 hr	400 hr	400 hr
Refrigerant	R454B		
Refrigeration Oil	New-PVE		
Additive	New stabilizer added		
Discharge Gas Temperature	120 ºC	50 ºC	65 ºC
Discharge Gas Pressure	High	Normal	Low

Table 14: Durability Test Results of Scroll Compressor (Wear Property of Sliding Parts)

Test No.	No. 1	No. 2	No. 3
Shaft (Gray Cast Iron)	Same as R32		
Bearing (PTFE Coating Bronze)	Same as R32		
Oldham (Al)	Same as R32		
Refrigeration Oil			
Appearance of Refrigeration Oil			
Acid Number	0.01 mg KOH/g	0.01 mg KOH/g	0.01 mg KOH/g
Fluorine ion	>1 mg/L	>1 mg/L	>1 mg/L
Trifluoroacetic ion	>1 mg/L	1 mg/L	>1 mg/L
Acetic Acid ion	>1 mg/L	>1 mg/L	>1 mg/L

5.4 Confirmation Results for Screw Compressor Reliability by HFO Refrigerant Drop-in Test

To verify compressor reliability for HFO refrigerant, an HFO refrigerant was dropped into an R1234yf screw compressor and a durability test was performed. Table 15 shows the test conditions and Table 16 shows the test results. Even at discharge gas temperature of 120℃ for which there is concern for refrigerant decomposition, no corrosion of parts was observed after the test. Also, the oil showed no increase in acid number after the test, and there was no acid formation derived from refrigerant decomposition product.

Table 15: Durability Test Conditions of Scroll Compressor

Test No.	No. 4
Operating Conditions	High Compression Ratio
Operating Time	2000 hr
Refrigerant	R1234yf
Refrigeration Oil	New-PVE
Additive	New stabilizer added
Discharge Gas Temperature	120 ºC
Discharge Gas Pressure	High

Table 16: Durability Test Results of Screw Compressor (Wear Property of Sliding Parts)

Test No.	No. 4
Shaft	Same as R134a
Bearing	Same as R134a
Refrigeration Oil	
Appearance of Refrigeration Oil	
Acid Number	0.01 mg KOH/g
Fluorine ion	>1 mg/L
Trifluoroacetic ion	>1 mg/L
Acetic acid ion	>1 mg/L

6. CONCLUSIONS

Product systems and compressors using either R32 and R134a refrigerants were charged with HFO and HFO blend refrigerants, and reliability was evaluated by a drop-in test.

- The HFO blend refrigerants containing R1234yf react with the surface of the aluminum alloy and reduces lubricity.
- It was found that HFO and HFO blend refrigerants generate more acid due to deterioration of stability than R32 refrigerant, and the acid that is generated corrodes the expansion valve.
- Adding a new stabilizer is effective to enhancing the stability of HFO and HFO blend refrigerants.
- For practical application, it is necessary to evaluate not only a simple element test as performed during refrigerant conversion in the past but also a reliability test of the actual system. Additionally, it is important to conduct field tests to sufficiently confirm lubrication oil, functional parts, etc., that are likely to affect the system during actual use conditions.

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ACKNOWLEDGMENTS

We would like to thank Idemitsu Kosan Co., Ltd. for providing the oils and cooperating in the oil analyses after the tests and lubricity tests.